Repeated Biomass Removal Affects Soybean Resource Utilization and Yield

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] producers in many regions of the USA are confronted with significant yield losses because of crop damage from white-tailed deer (*Odocoileus virginianus*). Our objectives were to quantify soybean resource utilization and yield responses to variety, row spacing, and simulated repeated biomass removal. Field research was conducted in 2000 and 2001 on a Quakertown silt loam soil (fine-loamy, mixed, mesic Typic Hapludult) near Pittstown, NJ. Biomass removal during early vegetative and vegetative/reproductive growth extended the soil wetness duration index on average by 1.5 and 2.9 d compared with the control from the 0- to 30- and 30- to 60-cm soil depths in 2000 and by 5.1 and 2.1 d in 2001. Biomass removal during early vegetative growth delayed pod maturity up to 7 d compared with the control, but biomass removal during reproductive growth hastened pod maturity by as much as 3 d. Averaged across row spacing and biomass removal, variety 'APK394NRR' yielded 12 and 24% lower than '93B53' in 2000 and 2001. In 2000, averaged across variety and biomass removal, the 20- and 41-cm row widths yielded 19 and 16% less than the 76-cm row width. Averaged across variety and row spacing, all biomass removal treatments lowered yield compared with the control except the midvegetative/early reproductive treatment in 2001 (661 vs. 663 g m^{-2}). The greatest yield reductions occurred (up to 89%) when biomass was removed repeatedly during vegetative and reproductive growth. Management implications for soybean producers include variety selection and row spacing to diminish the effects of deer damage.

Timing, intensity, and frequency of biomass removal affects soybean yield. Yield reduction is less sensitive to biomass removal during vegetative growth because soybean can develop new leaf area that can compensate for temporarily reduced assimilatory capacity. Singer (2001) reported that yield reductions in indeterminate soybean from removing the top third of the plant at V5 (Fehr and Caviness, 1977) were less than biomass removed at R4. Francoeur (1995) evaluated severe simulated deer damage in 1-m rows during vegetative and reproductive growth and concluded that damage imposed at V10 lowered yield in 1 of 2 yr but damage at R4 decreased yield in both years. Fehr et al. (1977) reported that yield of determinate cultivars was affected more than indeterminate cultivars from 100% defoliation when defoliation occurred from R2 through R6. Average yield loss from half-plant cutoff was similar for determinate (33%) and indeterminate (34%) cultivars, but there was a significant interaction with growth stage (Fehr et al., 1977).

Previous research has identified that reductions in light interception of defoliated treatments was related to yield reductions (Higley, 1992; Hunt et al., 1994; Haile et al., 1998). Hunt et al. (1994) concluded that removal of leaf area delayed the time to achieve a critical leaf area index (LAI) of 3.5, limiting light interception and dry matter accumulation. Haile et al. (1998) imposed defoliation treatments at R2 and concluded that yields were directly related to the light interception capacity of soybean canopies after defoliation. Klubertanz et al. (1996) reported that soybean subjected to simulated insect defoliation at R2 increased soil water content in both years of their 2-yr study and delayed senescence of lower leaves. Hintz et al. (1991) evaluated soybean response to stem cutoff and defoliation during vegetative development and reported that averaged across stage of development when treatments were imposed, the delay in maturity was greatest for plants injured by cutoff treatments and was least for defoliation treatments in the absence of stem cutoff.

Most of the published defoliation studies have focused on insect defoliation using either single-day or sequential defoliation approaches or simulated hail damage using different defoliation or stem removal techniques. Moreover, most defoliation/biomass removal studies have evaluated soybean response to defoliation in row spacings greater than 68 cm and do not simulate severe biomass removal. Our simulation technique was designed to mimic white-tailed deer damage. Ultimately, techniques similar to those presented by Singer et al. (2004) will be used to simplify the process of quantifying soybean yield loss from deer depredation. In the short-term, data are still required to determine biomass removal by management interactions on soybean responses. The objectives of our study were to quantify soybean resource utilization and yield responses to variety, row spacing, and repeated biomass removal during vegetative and reproductive growth.

MATERIALS AND METHODS

A 2-yr study evaluating biomass removal in no-tillage soybean was conducted in 2000 and 2001 on a Quakertown silt loam soil (fine-loamy, mixed, mesic Typic Hapludult) at the Rutgers University Snyder Research and Extension Farm near Pittstown, NJ (40°30′ N, 75°00′ W, elev. 170 m a.s.l.). A three factor treatment structure in a split-split-plot randomized complete block design with four replications was established. The main factor was indeterminate soybean variety, either Pioneer Brand '93B53' maturity group (MG) 3.5 or Agway 'APK394NRR' MG 3.9, the first split was three row spacings, 20-, 41-, and 76 cm, and the second split was biomass removal at V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive) and a control. Main plot area was 64.7 m^2, subplot area was 18.5 m^2 for the 20- and

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Abbreviations: DAP, days after planting; LAI, leaf area index; MG, maturity group; PAR, photosynthetically active radiation.

41-cm row spacing and 27.8 m^2 for the 76-cm row spacing, and sub-subplot area was 3.7 m^2 for the 20- and 41-cm row spacing and 5.6 m^2 for the 76-cm row spacing.

Soybean was planted using no-tillage techniques on 16 and 21 May in 2000 and 2001, respectively, at 518 700 seeds ha^{-1} using a no-tillage drill in the 20- and 41-cm row spacings, and a no-tillage planter in the 76-cm row spacing. Soybean followed corn (*Zea mays* L.) each year. Preemergence herbicides were used for weed control in combination with handweeding to maintain weed-free plots. Fertilizer was applied according to soil test recommendations. Biomass removal was accomplished using scissors by measuring the height of plants in each treatment and removing approximately 30% of the average height of each plant. Biomass from each clipping date was collected for each sub-subplot and dried in a forced-air oven at 70°C for at least 48 h. Biomass removal treatments were imposed using the growth stage of control plants as a reference.

Tensiometers were inserted in the row at V1 at the 30- and 60-cm soil depths in all sub-subplots in three replications in 2000 and four in 2001. Soil water potential measurements were made frequently with a pressure transducer (Marthaler et al., 1983) until the soil water pressure exceeded the air entry value of the porous cup (−800 mbar). In 2000, soil water tension measurements commenced on 21 June, 36 d after planting (DAP), and ended on 31 July, for a total of 29 measurements. In 2001, measurements started on 18 June, 28 DAP, and ended on 9 August, for a total of 40 measurements.

Light interception was measured on 1, 5, 7, 10, 17, 20, and 28 July; 5, 8, 11, 15, 21, and 25 August; 6, 14, 20, and 29 September in 2000; and 27 June; 3, 10, 18, 23, 27, and 30 July; 2, 7, 10, 15, 21, 24, and 30 August; 3, 6, 12, and 17 September; and 2 October in 2001 by taking the average of six parallel (Singer, 2001) measurements per plot, three along the base of the row and three in the middle of the row. All measurements were made between 1200 and 1430 h in full sun conditions using a 1-m line quantum sensor (Delta-T Devices Ltd, Cambridge, UK) to measure light interception of photosynthetically active radiation (PAR) below the canopy. A PAR sensor on a tripod was used to simultaneously measure incident light above the canopy. Light interception was calculated as the difference between incident and transmitted light divided by incident light.

Fifteen plants per sub-subplot were harvested after physiological maturity to determine pod number, seed per pod, seed weight, and seed yield. Pod maturity was monitored over time and pods were considered mature when 95% achieved their final color. Pod number and seed yield were converted to an area basis using harvest stand counts. Harvest stand count data were collected by counting all plants in each sub-subplot at R8. Soybean seed were dried in a forced-air oven at 70°C for at least 72 h and weighed to determine yield. Grain protein and oil composition were determined using NIR analytical methods. Air temperature and precipitation data were collected daily approximately 0.5 km from the experimental site.

For each year, sub-subplot, and depth response, the tensiometer time series was examined separately. Davidian and Giltinan's (1995) repeated measurement methodology guided our work. Using simple numerical analysis, we defined an estimator $x(t)$ to be the tensiometer reading at a given time. Without loss of generality $x(t)$ can be taken as positive with $x(t) = 0$ being wet and $x(t) = 800$ being dry. Scaling the reading from 0 to 1, a wetness index, $y(t)$, follows: $y(t) = 1 - x(t)/800$; integrating $y(t)$ over the period of the readings (here in days, with Period = Final day − Starting day), a wetness duration index was calculated. The wetness index is the equivalent period of complete saturation (wetness) if the plot started out completely wet and dried out completely at the end of the period (i.e., mathematically, a single square wave). A numerical trapezoidal rule for unequally spaced data was used to perform the integrations. The estimator is similar to that in Meek (2001). The light interception time series was also examined separately and approached similarly to the wetness index. Two duration indices were defined. The first represents the duration of light transmittance from the first day to the last day of light interception measurements (season). If $L(t)$ is the light interception at time t, then the corresponding transmittance is $T(t) = 1 - L(t)$, and the duration index is the definite integral of $T(t)$ over the period. The second index cuts off the definite integral when the average treatment achieves $T(t) = 0$, maximum light interception (minimum transmittance). For 2000, this occurred at 101 DAP, and in 2001 it occurred at 99 DAP.

Statistical significance of treatment effects and interactions were determined using fixed and random effects ANOVA in SAS (Littell et al., 2001). For the random effects model, rep and all rep interactions were considered random. The year effect was highly significant so a separate analysis is presented for each year. Least squares means for seed yield, pod number, seed per pod, and seed weight were adjusted using total biomass removal as a covariate in the analysis. The biomass removal analysis included stand density as a covariate. Preplanned contrasts and least square means were estimated. Means were separated using Fisher's protected LSD. All effects were considered significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Air temperatures during the study period were above normal in May and June of each year and below normal during July (Table 1). August air temperature in 2001 exceeded the normal temperature by 1.5°C. Precipitation in 2000 was close to normal except in July and August, when 32 mm below and 31 mm above normal occurred. In 2001, 76 mm precipitation above normal was received in June and 63 mm below normal occurred in August. No visible water stress occurred in 2001 because near or above normal precipitation occurred before August, when precipitation was below average.

Soil Water

The soil water wetness duration index in 2000 for the 0- to 30- and 30- to 60-cm soil depths was less than 12 and 19 d (Table 2), respectively. Soil water tension measurements were initiated on 21 June. The control and reproductive treatments had similar wetness duration indices (10.1 and 10.2 d). The midvegetative/early reproductive treatment depleted soil water faster than

Table 1. Mean monthly air temperature and precipitation in 2000 and 2001 near Pittstown, NJ.

	Air temperature			Precipitation		
Month	2000	2001	Normal†	2000	2001	Normal
	°C			mm		
May	16.2	16.4	15.0	119	116	117
June	20.6	21.6	20.2	98	183	107
July	21.3	21.2	23.0	92	104	124
August	20.8	23.7	22.2	130	36	99
September	17.1	18.3	17.9	105	104	99

† Normal data are average of previous 30 yr measured at a weather station 11 km from experimental site.

Table 2. Soybean soil water wetness duration index ANOVA results. Measurements start from 36 and 31 d after planting in 2000 and 2001 from the 0- to 30- and 30- to 60-cm soil depths for treatments subjected to different biomass removal, averaged across variety and row spacing near Pittstown, NJ.

		2000		2001	
Biomass removal treatment (TRT)†	***n***	**0 to 30**	**30 to 60**	**0 to 30**	**30 to 60**
		d			
Control	**24**	**10.1**	**15.0**	**28.5**	**34.7**
Early vegetative	**24**	**11.6**	**18.1**	**33.5**	**36.6**
Midvegetative/early reproductive	**24**	**9.5**	**16.2**	**29.1**	**35.4**
Reproductive	**24**	**10.2**	**15.3**	**28.4**	**35.3**
Vegetative and reproductive	**24**	**11.5**	**17.6**	**33.7**	**37.0**
LSD (0.05)		**0.6**	**0.5**	**1.0**	**1.0**
ANOVA	***df***	$P > F$			
Variety	**1**	**0.2804**	**0.0262**	**0.3989**	**0.1855**
Row spacing	**2**	**0.4082**	**0.0652**	**0.1828**	**0.3012**
Variety × row spacing	**2**	**0.8140**	**0.8877**	**0.7475**	**0.8732**
TRT	**4**	**0.0001**	**0.0001**	**0.0001**	**0.0081**
Variety × TRT	**4**	**0.9553**	**0.2272**	**0.6849**	**0.2569**
Row spacing × TRT	**8**	**0.8568**	**0.1011**	**0.1905**	**0.1635**
Variety × row spacing × TRT	**8**	**0.8209**	**0.3896**	**0.5333**	**0.7975**

† V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive).

either of those two treatments and had a wetness duration index value of 9.5 d. Singer (2001) reported compensatory growth of V5 and R1 biomass removal treatments, which may have occurred because of rapid canopy development subsequent to biomass removal. The rapid canopy recovery in the midvegetative/early reproductive treatment may have contributed to the more rapid depletion of soil water compared with the control. Klubertanz et al. (1996) reported that compensatory growth was observed in their defoliation treatments that resulted in more leaves in defoliated plants than predicted. In contrast, the early vegetative and vegetative/reproductive treatments exhibited delayed soil water use (11.6 and 11.5 d) compared with the control because of the repeated biomass removal and failure to maintain an adequate canopy for radiation interception. At the second soil depth, the wetness duration index for variety was significant. Averaged across row spacing and treatment, 93B53 had a shorter soil water duration index compared with APK394NRR (15.7 vs. 17.1 d). A similar biomass removal treatment response was observed for the second soil depth. The only difference was between the midvegetative/early reproductive treatment and the control, which had a slightly longer rather than shorter duration index compared with the control (16.2 vs. 15.0 d).

In 2001, tensiometer measurements were initiated 31 d after planting. No difference was detected in the wetness duration index among the control, midvegetative/early reproductive, and reproductive treatments from the 0- to 30-cm soil depth. Similarly, no difference was detected between the early vegetative and vegetative/reproductive treatments. Apparently, removing biomass early and repeatedly during vegetative growth consistently delayed soil water depletion compared with biomass removal treatments that occurred later during soybean development. Klubertanz et al. (1996) reported that defoliation increased soil water percentage in both years of their 2-yr study, showing that defoliated stressed plants conserve more water than nondefoliated stressed plants. Treatment differences at the second soil depth generally followed a similar pattern as the previous year, whereby no differences were detected among the control, midvegetative/early reproductive, and reproductive treatments. Likewise, the early vegetative and vegetative/reproductive treatments had similar wetness duration indices. The wetness duration index difference between the average of the control, midvegetative/early reproductive, and reproductive treatments and the early vegetative and vegetative/reproductive treatments was 1.7 d.

Light Transmittance

Light transmittance to the minimum transmittance was affected by variety, row spacing, biomass removal treatment, and a variety × treatment interaction in 2000 (Table 3). The minimum transmittance occurred for all treatments at 101 DAP. At 101 DAP, all row spacings were intercepting approximately 95% of the incident light, while the range in biomass removal treatment light interception was from 88 to 98%. The 20-cm row spacing had a lower transmittance index than the 41-cm (p = 0.0307) and 76-cm (p = 0.0002) row spacings, while the 41- and 76-cm row spacings were also different (p = 0.0169). The same trend continued for the total season transmittance index among the different row spacings (Table 3). A variety × treatment interaction occurred for minimum transmittance because the midvegetative/early reproductive and reproductive treatments had different transmittance indices for 93B53 but similar indices for APK394NRR. These differences may be attributed to morphology and maturity group differences. The APK394NRR variety probably partitioned more assimilate to replace leaf area that was removed at the midvegetative/early reproductive treatment than 93B53, which most likely transitioned to reproductive development sooner and limited leaf area replacement compared with APK394NRR. Additionally, Singer (2001) reported differences in branch number for row spacing and biomass removal treatments. It is possible that varietal morphological differences also contributed to the quantity of transmitted light that reached the soil because of different branching patterns and canopy architecture. Transmittance was lower for treatments that had delayed biomass removal, such as the control, mid-

Table 3. Soybean light transmittance index ANOVA results for the number of days to the minimum transmittance and the total seasonal transmittance starting at 46 and 37 days after planting (DAP) in 2000 and 2001 and ending at 136 and 132 DAP for row spacing and variety × biomass removal treatment least squares means near Pittstown, NJ.

Factor	n	2000 Minimum	2000 Season†	2001 Minimum	2001 Season
		d			
Row spacing					
20 cm	40	17.9	23.7(3.17)	17.7	32.1
40 cm	40	19.1	25.3(3.23)	18.9	31.5
76 cm	40	20.5	26.8(3.29)	20.3	32.7
Variety × biomass removal treatment (TRT)					
93B53					
Control	12	13.3	18.2(2.90)	13.2	21.0
Early vegetative (veg.)‡	12	20.5	23.8(3.17)	20.4	31.3
Midveg./early reproductive	12	17.2	20.8(3.03)	17.1	22.2
Reproductive	12	15.1	24.8(3.21)	14.8	28.5
Veg. and reproductive	12	23.8	33.7(3.52)	23.5	46.7
APK394NRR					
Control	12	16.5	22.0(3.09)	16.4	23.8
Early veg.	12	21.9	25.3(3.23)	21.8	35.7
Midveg./early reproductive	12	18.9	22.6(3.12)	18.8	25.4
Reproductive	12	19.9	30.9(3.43)	19.5	36.3
Veg. and reproductive	12	24.6	35.8(3.58)	24.2	50.3
LSD (0.05)§		1.1	(0.06)	1.0	2.4
ANOVA	df	$P > F$			
Variety	1	0.0097	0.0575	0.0093	0.0358
Row spacing	2	0.0008	0.0015	0.0010	0.7004
Variety × row spacing	2	0.1687	0.1136	0.1729	0.2008
TRT	4	0.0001	0.0001	0.0001	0.0001
Variety × TRT	4	0.0021	0.0247	0.0017	0.2376
Row spacing × TRT	8	0.0582	0.1846	0.0534	0.8223
Variety × row spacing × TRT	8	0.1189	0.4791	0.1239	0.4464

† Statistical analysis was conducted on log transformed data, which are presented in parentheses.
‡ V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive).
§ LSD compares biomass removal TRT means for the same variety.

vegetative/early reproductive, and reproductive. A similar generalization was also valid for the seasonal transmittance index. The early vegetative and reproductive treatments of 93B53 had a similar transmittance index, while the control and midvegetative/early reproductive treatments for APK394NRR were similar. Apparently, the 93B53 early vegetative and APK394NRR midvegetative/early reproductive treatments intercepted more light after the minimum transmittance occurred. A total seasonal index difference of 15.5 and 13.8 d of transmittance occurred between the control and vegetative/reproductive treatments for 93B53 and APK394NRR.

Similar responses were observed in 2001 for the minimum transmittance index among row spacings (Table 3). The minimum transmittance occurred at 99 DAP for all treatments. At 99 DAP, averaged across variety and biomass removal, all row spacings were intercepting approximately 84% of incident light and biomass removal treatments, averaged across variety and row spacing, were intercepting from 69 to 97% of incident light. A variety by treatment interaction was detected because the minimum transmittance index for the midvegetative/early reproductive and reproductive treatments were different for 93B53 but similar for APK394NRR. The longer MG (3.9 vs. 3.5) for APK394NRR vs. 93B53 extended the vegetative period and allowed more canopy regrowth after biomass removal. No differences were detected among row spacings for the total seasonal transmittance index in 2001, although varietal differences occurred. Averaged across row spacing and biomass removal treatment, 93B53 had a lower transmittance index (29.9 d) compared with APK394NRR (34.3). No variety × treatment interaction was observed in 2001 for the seasonal transmittance index, but biomass removal treatment was significant. Similar transmittance indices occurred for the control and the midvegetative/early reproductive treatments (22.4 and 23.8 d), and for the early vegetative and reproductive treatments (33.5 and 32.4 d). The vegetative/reproductive treatment had the greatest transmittance duration index (48.5 d) among biomass removal treatments.

Plant Height and Biomass Removal

Biomass removal treatment and a variety × treatment interaction affected plant height in 2000 (Table 4). Averaged across row spacing, the control treatments for 93B53 and APK394NRR were 82 and 88 cm, 14 and 9 cm taller than the mean height of the early vegetative and midvegetative/early reproductive treatments. The 93B53 and APK394NRR control plant height exceeded the reproductive and vegetative/reproductive treatments by 28 and 36 cm and 34 and 43 cm, respectively. Treatment, variety × treatment, and row spacing × treatment interactions were significant in 2000 for biomass removal. Averaged across row spacing, biomass removal in 93B53 was 67 g m^{-2} lower between the reproductive and vegetative/reproductive treatments compared with only 40 g m^{-2} for APK394NRR. The row spacing × treatment interaction resulted from smaller plants in the wide row spacing that reduced biomass removal for the reproductive and vegetative/reproductive treatments. For example, averaged across variety, 217, 205, and 155 g m^{-2} bio-

Table 4. ANOVA results for plant height at maturity and seasonal biomass removal for two soybean varieties planted in three row spacings (RS, cm) subjected to different biomass removal treatments in 2000 and 2001 near Pittstown, NJ.

Variety	RS	Biomass removal treatment (TRT)	n	Plant height 2000	Plant height 2001	Biomass removal 2000	Biomass removal 2001
				cm	cm	$g\ m^{-2}$	$g\ m^{-2}$
93B53	20	Control	4	79	72	–	–
		Early vegetative (veg.)	4	71	57	17	37
		Midveg./early reproductive	4	66	62	50	87
		Reproductive	4	57	37	225	401
		Veg. and reproductive	4	45	33	144	216
	40	Control	4	82	77	–	–
		Early veg.	4	68	63	17	40
		Midveg./early reproductive	4	71	67	42	71
		Reproductive	4	55	49	198	358
		Veg. and reproductive	4	46	31	132	191
	76	Control	4	85	83	–	–
		Early veg.	4	67	59	19	27
		Midveg./early reproductive	4	60	61	51	39
		Reproductive	4	51	43	166	315
		Veg. and reproductive	4	46	31	111	130
APK394NRR	20	Control	4	87	85	–	–
		Early veg.	4	83	60	13	53
		Midveg./early reproductive	4	80	72	35	87
		Reproductive	4	50	38	210	454
		Veg. and reproductive	4	43	31	173	218
	40	Control	4	90	89	–	–
		Early veg.	4	79	64	14	28
		Midveg./early reproductive	4	80	79	37	53
		Reproductive	4	51	46	212	326
		Veg. and reproductive	4	44	34	155	189
	76	Control	4	88	94	–	–
		Early veg.	4	77	71	12	28
		Midveg./early reproductive	4	75	81	40	64
		Reproductive	4	61	41	145	410
		Veg. and reproductive	4	48	45	120	149
		LSD (0.05)‡		6	7	11	34
		LSD (0.05)§		4	5	8	24
		ANOVA	df	$P > F$			
		Variety (VAR)	1	0.248	0.254	0.539	0.330
		Row spacing (RS)	2	0.432	0.105	0.137	0.099
		VAR × RS	2	0.491	0.038	0.489	0.588
		TRT	4	0.000	0.000	0.000	0.000
		VAR × TRT	4	0.000	0.002	0.000	0.276
		RS × TRT	8	0.062	0.466	0.000	0.002
		VAR × RS × TRT	8	0.274	0.725	0.337	0.243

† V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive).
‡ LSD compares biomass removal TRT means for the same variety and row spacing.
§ LSD compares biomass removal TRT means for the same row spacing.

mass were removed in the 20-, 41-, and 76-cm row widths for the reproductive only treatment. Singer (2001) also reported lower biomass removal in a 76-cm row width compared with 18- or 20-cm row widths using a similar biomass removal technique.

In 2001, main effects of row spacing and treatment were significant, as well as variety × row spacing and variety × treatment interactions for plant height. The variety × row spacing interaction was observed because plant height in the 20-, 41-, and 76-cm row spacings for 93B53, averaged across treatment, was 52, 57, and 55 cm compared with 57, 62, and 66 cm for APK394NRR. The variety × treatment interaction was observed because, averaged across row spacing, plant height of the midvegetative/early reproductive treatment of APK394NRR increased 12 cm compared with the early vegetative treatment and only 3 cm for the same treatment comparison for 93B53. This result is consistent with MG differences, whereby the longer season variety (APK394NRR) continued vegetative growth longer than the shorter season variety. Treatment and a row spacing × treatment interaction were significant for biomass removal. The interaction was significant because biomass removal, averaged across variety, was 343 and 194 $g\ m^{-2}$ for the reproductive and vegetative/reproductive treatments in the 41-cm row spacings and 364 and 140 $g\ m^{-2}$ for the 76-cm row spacings. Averaged across variety, all comparisons among biomass removal treatments for the same row spacing were significantly different.

Maturity

Control treatments for 93B53 and APK394NRR reached 95% pod maturity on 3 and 8 Oct. 2000. Variety, treatment, and a variety × treatment interaction were significant. Biomass removal at the early vegetative and the midvegetative/early reproductive growth stages delayed maturity for both varieties (Table 5). Nevertheless, biomass removal during reproductive growth resulted in the same maturity as the control for 93B53 and accelerated maturity by more than 3 d for APK394NRR compared with the control. Biomass removal during

Table 5. ANOVA results for pod maturity in 2000 and 2001 for two soybean varieties subjected to different biomass removal treatments, averaged across row spacing near Pittstown, NJ.

Variety	Biomass removal treatment (TRT)†	*n*	2000	2001
			d	
93B53	Control	12	0.0	0.0
	Early vegetative (veg.)	12	+6.9	+6.4
	Midveg./early reproductive	12	+4.9	+1.7
	Reproductive	12	−0.1	+0.2
	Vegetative and reproductive	12	+1.6	+2.7
APK394NRR	Control	12	0.0	0.0
	Early vegetative (veg.)	12	+5.3	+5.7
	Midveg./early reproductive	12	+2.3	+1.3
	Reproductive	12	−3.3	−0.1
	Vegetative and reproductive	12	−0.4	+4.0
	LSD (0.05)		1.0‡	0.6§
	ANOVA	*df*	$P > F$	
	Variety (VAR)	1	0.044	0.782
	Row spacing (RS)	2	0.976	0.601
	VAR × RS	2	0.250	0.410
	TRT	4	0.000	0.000
	VAR × TRT	4	0.019	0.110
	RS × TRT	8	0.489	0.741
	VAR × RS × TRT	8	0.243	0.154

† V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive).
‡ LSD compares biomass removal TRT means for the same variety.
§ LSD compares biomass removal TRT means.

vegetative/reproductive growth stages delayed maturity slightly for 93B53 while APK394NRR and the control were similar. Removing biomass early and repeatedly during the growing season as was accomplished in the vegetative/reproductive treatment, in which biomass was removed on six separate dates, probably downregulated sink demand earlier during growth to accommodate reduced source supply. The reproductive only treatment, where biomass removal occurred initially at R1, may not have altered the source/sink relationship to accommodate the reduced capacity of this treatment to meet the seed fill demand. Biomass removal in this treatment also occurred at R4 and at R6, which removed much of the photosynthetic capacity to supply assimilate or remobilize nutrients from the canopy, which probably contributed to the abbreviated effective seed filling period. Additionally, only 27 mm of precipitation was received at the experimental site from 15 August through 12 September, which probably affected the longer season variety (APK394NRR) more than the shorter season variety (93B53).

In 2001, control treatments for 93B53 and APK394NRR reached 95% pod maturity on 4 and 6 October. Pod maturity differences were limited to biomass removal treatments. Averaged across variety and row spacing, only the reproductive treatment had similar pod maturity as the control. The early vegetative, midvegetative/early reproductive, and vegetative/reproductive treatments delayed maturity by 6.1, 1.5, and 3.4 d, respectively. Hintz et al. (1991) reported a delay in maturity of 5 and 8 d when 33 and 66% of the main stem was removed without additional defoliation, averaged across growth stage (V3 and V6). The favorable September temperature and precipitation conditions probably extended the seed filling period and delayed pod maturity for these treatments.

Yield and Yield Components

Main effects of variety, row spacing, and biomass removal treatment were significant for yield in 2000 (Table 6). The 93B53 variety yielded 12% greater than APK394NRR, averaged across row spacing and biomass removal treatment. Averaged across variety and biomass removal treatment, the 76-cm row width yielded 19 and 16% greater than the 20- and 41-cm row widths ($P = 0.000$ and 0.001). Singer (2001) reported yield reductions of 49 and 36% for 18- or 20-cm row spacings compared with 76-cm row spacings, averaged across two growing seasons, when biomass removal occurred at V5 + R1 + R4. These results imply that soybean planted in 76-cm rows maintain yield more than soybean planted in row widths ranging from 18 to 41 cm when severe biomass removal occurs. Averaged across variety and row spacing, biomass removal during early vegetative, midvegetative/early reproductive, reproductive, and vegetative/reproductive treatments yielded 37, 25, 79, and 89% less than the control, respectively.

Yield components varied in their sensitivity to different factors in 2000. Biomass removal treatments only affected pod density (Table 6). Averaged across variety and row spacing, pod density declined from 1479 pods m^{-2} for the control to 1061, 1191, 900, and 603 pods m^{-2} for the early vegetative, midvegetative/early reproductive, reproductive, and vegetative/reproductive treatments. Seed number pod^{-1} revealed a three-way interaction (Table 6). In the 20-cm row spacing, similar seed number was observed for 93B53 among the control, early vegetative, and midvegetative/early reproductive treatments (2.54, 2.46, and 2.48 seed pod^{-1}). In the same row spacing for APK394NRR, seed number between the early vegetative and midvegetative/early reproductive treatments was similar (2.57 and 2.64 seed pod^{-1}), but both were lower than the control (2.79 seed pod^{-1}). In the 41-cm row spacing for 93B53, seed number was

Table 6. ANOVA results, averaged across row spacing, for yield and yield components for two soybean varieties subjected to different biomass removal treatments in 2000 near Pittstown, NJ.

Factor	*n*	Yield	Pod no.	Seed no.	Seed wt.	Protein	Oil
Variety		g m^{-2}	no. m^{-2}	no. pod^{-1}	g 100 seed^{-1}	g kg^{-1}	
93B53	60	338	1071	2.27	14.2	357	179
APK394NRR	60	299	1023	2.41	12.6	367	174
Biomass removal treatment (TRT)†							
Control	24	589	1479	2.65	15.1	360	180
Early vegetative (veg.)	24	371	1061	2.50	14.1	361	177
Midveg./early reproductive	24	444	1191	2.60	14.8	360	179
Reproductive	24	124	900	2.01	12.1	360	175
Veg. and reproductive	24	64	603	1.93	11.0	370	169
LSD (0.05)‡		20	123	0.09	0.4	5	4
ANOVA	*df*	*P* > *F*					
Variety (VAR)	1	0.002	0.336	0.049	0.220	0.130	0.245
Row spacing (RS)	2	0.001	0.283	0.284	0.076	0.709	0.149
VAR × RS	2	0.643	0.455	0.334	0.391	0.235	0.840
TRT	4	0.000	0.000	0.000	0.000	0.000	0.000
VAR × TRT	4	0.562	0.659	0.542	0.000	0.007	0.068
RS × TRT	8	0.650	0.770	0.799	0.942	0.123	0.239
VAR × RS × TRT	8	0.070	0.268	0.030	0.269	0.146	0.949

† V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive).

‡ LSD compares biomass removal TRT means.

similar for the control and the midvegetative/early reproductive treatments (2.50 and 2.54 seed pod^{-1}). For APK394NRR in the 41-cm row spacing, seed number was maintained in the early vegetative and midvegetative/early reproductive treatments compared with the control (2.67, 2.61, and 2.67 seed pod^{-1}). In the 76-cm row spacing, seed number was maintained in the early vegetative and midvegetative/early reproductive treatments compared with the control for 93B53 (2.48, 2.56, and 2.62 seed pod^{-1}) and between the control and midvegetative/early reproductive treatments for APK394NRR (2.78 and 2.77 seed pod^{-1}). The vegetative/reproductive treatment had greater seed number pod^{-1} than the reproductive only treatment at the 76-cm row spacing for 93B53 (2.07 vs. 1.90 seed pod^{-1}). The opposite response occurred for APK394NRR at the same row spacing (1.96 vs. 2.30 seed pod^{-1}).

Seed weight exhibited a variety × biomass removal treatment interaction (Table 6). The interaction occurred because seed weight, averaged across row spacing, when biomass removal occurred during early vegetative, midvegetative/early reproductive, reproductive, and vegetative/reproductive treatments in 93B53 were lower than the control (15.3, 15.7, 12.7, 11.2 vs. 16.3 g 100 seed^{-1}), compared with APK394NRR (12.9, 13.9, 11.5, 10.9 vs. 13.9 g 100 seed^{-1}), where the control and midvegetative/early reproductive treatments had similar seed weights. Seed weights were reduced by 31 and 22%, respectively, for the vegetative/reproductive treatment for 93B53 and APK394NRR compared with the controls.

A variety × treatment interaction was also observed for protein concentration in 2000 (Table 6). Seed protein concentrations were similar for 93B53 between the control (354 g kg^{-1}) and biomass removal at the early vegetative, midvegetative/early reproductive, and reproductive treatments (359, 357, and 350 g kg^{-1}), but protein concentration was higher for the vegetative/reproductive treatment (366 g kg^{-1}). In contrast, protein concentrations were similar among the control, early vegetative, and midvegetative/early reproductive treatments for APK394NRR (365, 363, and 364 g kg^{-1}) and higher in the reproductive and vegetative/reproductive treatments (371 and 374 g kg^{-1}). McAlister and Krober (1958) reported similar and 3% lower protein concentrations when 40 and 80% defoliation occurred when defoliation treatments were applied when plants had an occasional flower in the terminal inflorescences of the main axes or branches. Biomass removal during vegetative/reproductive growth increased seed protein concentrations 3 and 2% for 93B53 and APK394NRR, respectively. Seed oil concentration was affected by biomass removal treatment (Table 6). Averaged across variety and row spacing, the control and midvegetative/early reproductive treatments had similar oil concentrations (180 and 179 g kg^{-1}) while the vegetative/reproductive treatment (169 g kg^{-1}) had the lowest concentration.

In 2001, variety and biomass removal treatment affected yield (Table 7). Averaged across row spacing and biomass removal treatment, APK394NRR yielded 24% less than 93B53. Averaged across variety and row spacing, the midvegetative/early reproductive and control treatments produced similar yields. The early vegetative, reproductive, and vegetative/reproductive treatments yielded 24, 57, and 77% less than the control. Pod density was also affected by variety and biomass removal treatment and followed the same pattern as yield (Table 7). Averaged across row spacing and biomass removal treatment, APK394NRR had 19% fewer pods m^{-2} than 93B53. Averaged across variety and row spacing, pod density was reduced 15, 37, and 56% for the early vegetative, reproductive, and vegetative/reproductive treatments compared with the control. Similar seed number per pod occurred in the control, early vegetative, and reproductive treatments (Table 7). Seed number per pod increased 5% for the midvegetative/early reproductive and decreased 11% for the vegetative/reproductive treatment compared with the control. A variety × treatment interaction was observed for seed weight (Table 7). Sim-

Table 7. ANOVA results, averaged across row spacing, for yield and yield components for two soybean varieties subjected to different biomass removal treatments in 2001 near Pittstown, NJ.

Factor	*n*	Yield	Pod no.	Seed no.	Seed wt.	Protein	Oil
Variety		g m^{-2}	no. m^{-2}	no. pod^{-1}	g 100 seed^{-1}	g kg^{-1}	
93B53	60	514	1565	2.30	13.8	327	194
APK394NRR	60	390	1264	2.39	12.6	334	185
Biomass removal treatment (TRT)†							
Control	24	661	1785	2.38	15.3	339	190
Early vegetative (veg.)	24	504	1519	2.36	14.0	325	189
Midveg./early reproductive	24	663	1861	2.50	14.2	338	188
Reproductive	24	284	1127	2.37	11.6	326	192
Veg. and reproductive	24	149	780	2.11	10.7	326	189
LSD (0.05)‡		94	264	0.09	0.5	5	NS
ANOVA	*df*	$P > F$					
Variety (VAR)	1	0.000	0.015	0.264	0.000	0.220	0.320
Row spacing (RS)	2	0.476	0.680	0.221	0.126	0.602	0.668
VAR × RS	2	0.088	0.055	0.368	0.174	0.902	0.522
TRT	4	0.000	0.000	0.000	0.000	0.000	0.072
VAR × TRT	4	0.696	0.730	0.295	0.000	0.003	0.629
RS × TRT	8	0.260	0.271	0.163	0.233	0.439	0.966
VAR × RS × TRT	8	0.304	0.298	0.780	0.677	0.157	0.385

† V1 + V3 + V6 (early vegetative), V6 + R1 (midvegetative/early reproductive), R1 + R4 + R6 (reproductive), and (V1 + V3 + V6) + (R1 + R4 + R6) (vegetative and reproductive).
‡ LSD compares biomass removal TRT means.

ilar seed weights for 93B53 and APK394NRR were observed for the early vegetative and midvegetative/early reproductive treatments, but these were 8 and 6% lower than the controls. Seed weight for the vegetative/reproductive treatment in 93B53 and APK394NRR was 34 and 25% lower than the control. The difference in seed weight between the reproductive and vegetative/reproductive treatments in 93B53 and APK394NRR was 9 and 6%, respectively. A variety × treatment interaction was also observed for protein concentration (Table 7). No difference was detected between the control and the midvegetative/early reproductive treatment for either 93B53 or APK394NRR and no difference was detected between the early vegetative and vegetative/reproductive treatments for either variety. The interaction occurred because the reproductive treatment in 93B53 had a lower (315 g kg^{-1}) protein concentration compared with the midvegetative/early reproductive (338 g kg^{-1}) and for APK394NRR the two treatments had similar protein concentration (336 and 339 g kg^{-1}). Seed oil concentration was not affected by variety, row spacing, or biomass removal treatment in 2001 (Table 7).

CONCLUSIONS

Variety and biomass removal affected soybean yield. Row spacing effects are more pronounced in years when soil water is limiting. Some evidence indicates that MG III soybean maintains yield in 76 cm compared with 20-cm row widths when repeated biomass removal occurs when soil water is limiting, but additional research is needed to strengthen this relationship. Although biomass removal during vegetative and vegetative/reproductive growth delayed soil water depletion, smaller plants with reduced capacity to capture solar radiation limited the plants' ability to utilize resources efficiently. This occurred despite a longer reproductive period for certain treatments because of delayed pod maturity. Biomass removal at midvegetative/early reproductive growth stages was the least injurious treatment. Reductions in pod number, seed number, and seed weight all contributed to lower yield in response to biomass removal. The yield losses we report here, up to 89%, are more representative of yield losses soybean producers incur in areas where high deer densities occur.

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